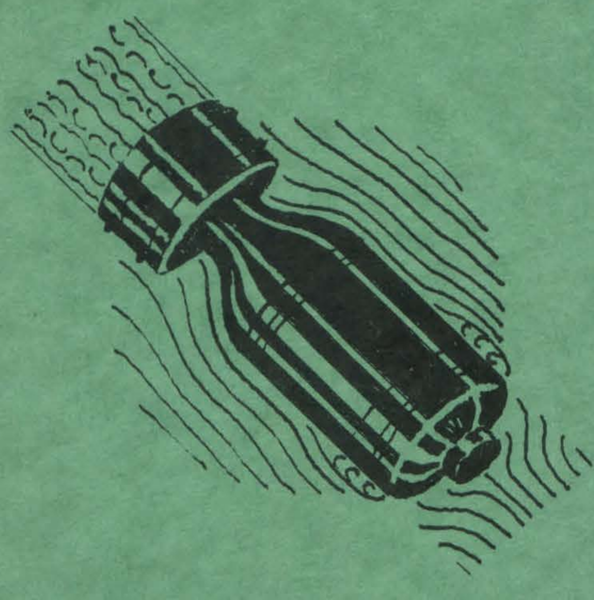
TE: This copy not to be released
r security regulations write
lowing on copy issued: "Regraded
classified ltr 4/27/56 Dept. Army
dj. Gen.) Ref. AGAO-S-3.12.1
Security J-1972

CONFIDENTIAL

OFFICE OF SCIENTIFIC RESEARCH & DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION SIX-SECTION 6.1

Regraded Unclassified 4/27/56
Ltr Dept of Army (Adj. Gen.)
Ref. AGAO-S-312.1 Security J-1972

FORCE TESTS
OF THE
4.5" ROCKET, T38E3



THE HIGH SPEED WATER TUNNEL
CALIFORNIA INSTITUTE OF TECHNOLOGY.
PASADENA, CALIFORNIA

SECTION Nº 6.1-Sr 207-1919
LABORATORY Nº ND-41

CONFIDENTIAL

COPY Nº 126

CONFIDENTIAL

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT
NATIONAL DEFENSE RESEARCH COMMITTEE
DIVISION SIX – SECTION 6.1

FORCE TESTS

OF THE

4.5" ROCKET, T38E3

ROBERT T. KNAPP

OFFICIAL INVESTIGATOR

THE HIGH SPEED WATER TUNNEL
AT THE
CALIFORNIA INSTITUTE OF TECHNOLOGY
HYDRODYNAMICS LABORATORY
PASADENA, CALIFORNIA

Section No. 6.1-sr207-1919

Laboratory No. ND-41

May 1, 1945

Report Prepared by

Gerald B. Robison
Hydraulic Engineer

CONFIDENTIAL

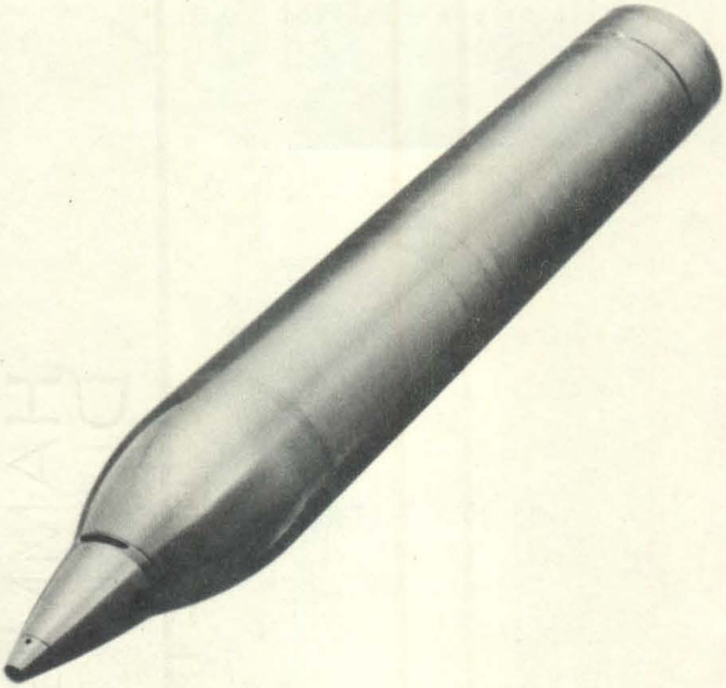


FIG. 1 – 2" DIAMETER MODEL OF 4.5" H.E. ROCKET, T38E3

FIG. 2 – 2" DIAMETER MODEL OF 4.5" H.E. ROCKET, T38E3

FORCE TESTS

OF THE

4.5" ROCKET, T38E3

PURPOSE OF TEST

This report covers the tests of a 2" diameter model of the 4.5" H.E. Rocket, T38E3, to determine the force and moment coefficients and the location of the center of pressure. The tests were made in the 14" diameter working section of the High Speed Water Tunnel at the California Institute of Technology. The work was authorized by a letter of January 31, 1944, from Dr. E. H. Colpitts, Chief of Section 6.1, National Defense Research Committee, New York City.

DESCRIPTION OF MODEL AND PROTOTYPE

Figures 1, 2, and 3 are views of the 2" diameter model. Indents and screw openings are visible in the fuse cap, and the construction of nozzles in the base is also shown. An outline

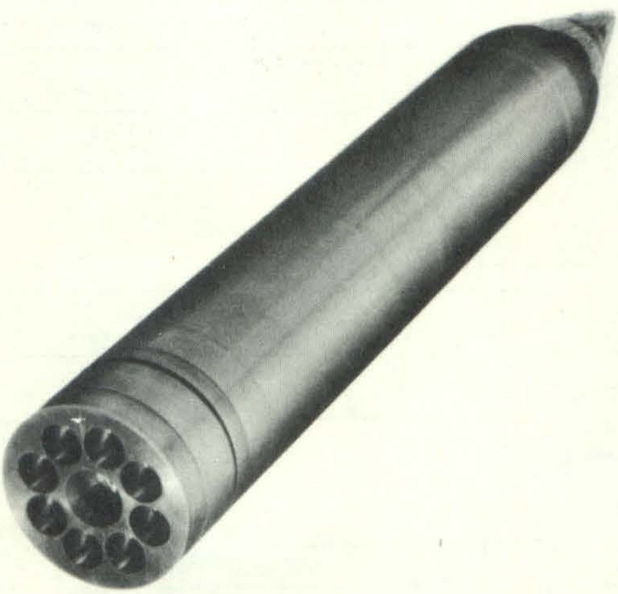


FIG. 3 – 2" DIAMETER MODEL OF 4.5" H.E. ROCKET SHOWING NOZZLES

drawing of the model is presented in Figure 4. Comparative outlines of the 5" SSR Rocket, and 3.5" Rocket with Nose No. 54, referred to herein, are shown in Figure 5.

Data pertaining to the prototype were given as follows:

Length overall	31.440 inches
Maximum diameter	4.515 inches
Distance, nose to center of gravity	16.19 inches
Weight without motor powder	42.5 pounds
Velocity at 70° Fahrenheit	830.0 ft/sec

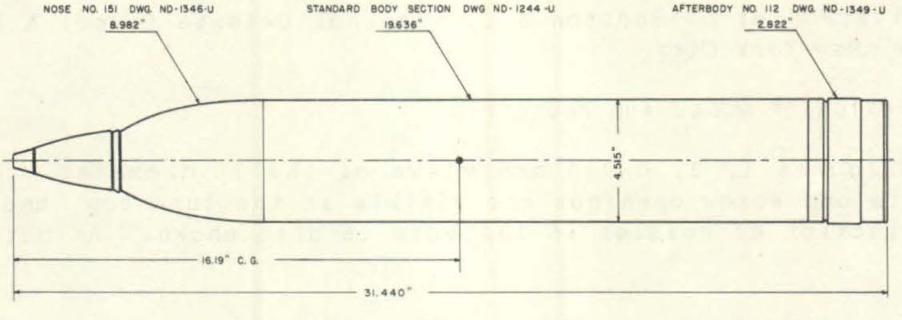


FIG. 4 — OUTLINE DRAWING OF 4.5" H.E. ROCKET, T38E3

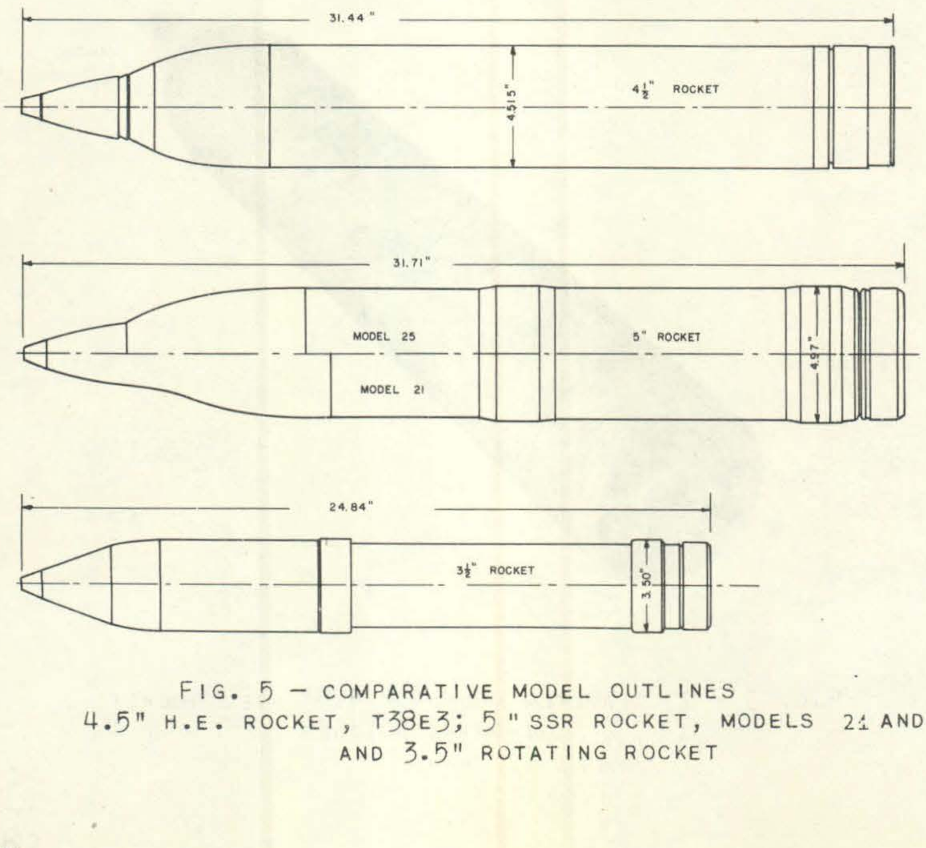


FIG. 5 — COMPARATIVE MODEL OUTLINES
4.5" H.E. ROCKET, T38E3; 5" SSR ROCKET, MODELS 21 AND 25;
AND 3.5" ROTATING ROCKET

TEST RESULTS

The results of the tests are shown in Figures 6 to 8, inclusive. These include flow diagrams obtained from model performance in the Polarized Light Flume.

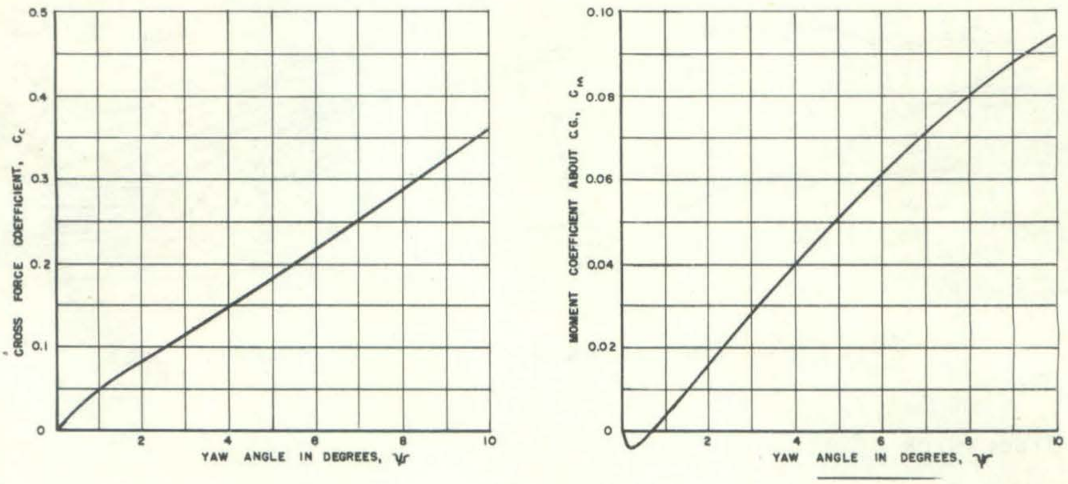


FIG. 6 — 4.5" H.E. ROCKET, T38E3
RELATION OF CROSS FORCE AND MOMENT COEFFICIENTS TO YAW ANGLE

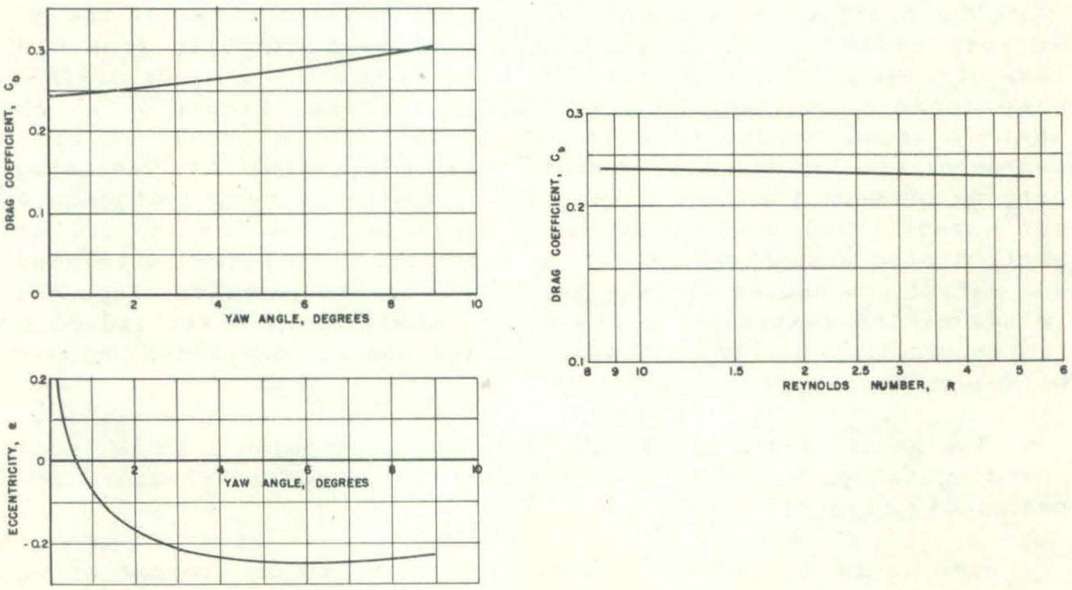


FIG. 7 — 4.5" H.E. ROCKET, T38E3
RELATION OF DRAG COEFFICIENT TO YAW ANGLE AND REYNOLDS NUMBER AND OF ECCENTRICITY TO YAW ANGLE

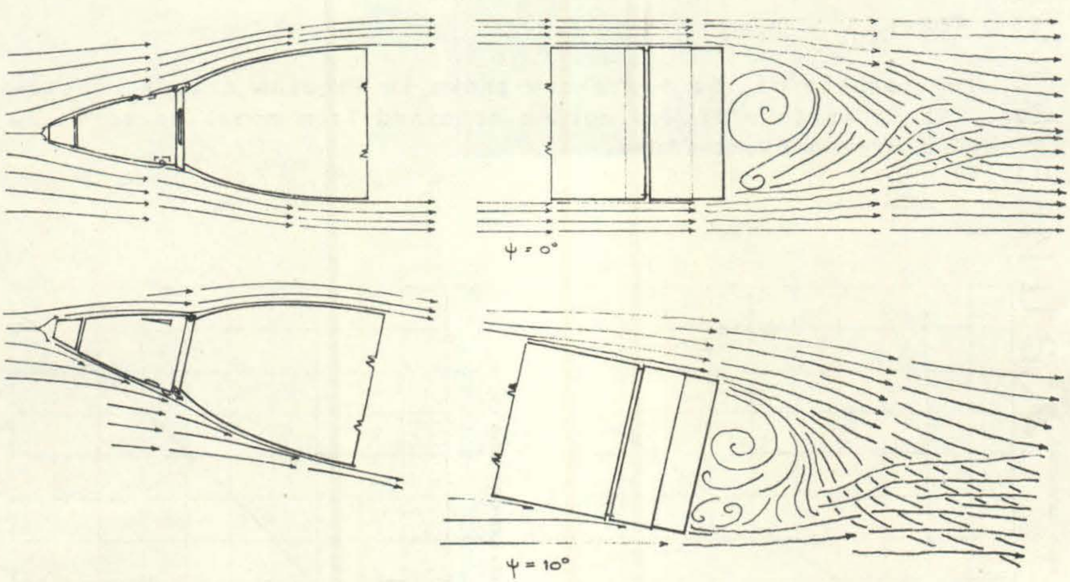


FIG. 8 – FLOW DIAGRAMS OF 4.5" H.E. ROCKET, T38E3

DISCUSSION OF RESULTS

Definition of terms, coefficient and center-of-pressure eccentricity formulae, and a general discussion of static stability are given in the Appendix to this report.

The coefficient curves have resemblances to those of the 5" Rocket, tested previously, as may have been expected from the general similarity of their shape. See Figure 5. A minor difference appears in the moment coefficient curve, Figure 6, which shows a small amount of static stability up to about 3/4 of a degree of yaw for the 4.5" Rocket. This minor stability was noted only because of readings taken at 1/2 degree of yaw, a procedure not normally followed. However, it may be noted that a similar small static stability was obtained for the 3.5" Rocket with Nose No. 54* at yaw angles of less than $1\text{-}1/2^{\circ}$. The positive slope and values of the remainder of the moment coefficient curve indicate the static instability of the projectile and its increasing amount with increase of yaw angle.

The small static stability for yaw angles below $3/4^{\circ}$ is indicated again by the positive values of the center-of-pressure eccentricity, Figure 7.

The cross force coefficient, Figure 6, is an average of 5% greater than Model 25, and 10% greater than Model 21 of the 5" Rocket.

* "Water Tunnel Tests of the 3.5" Rotating Rocket", Section No. 6.1-sr207-1270, April 21, 1944

The drag coefficient, C_D, is shown for angles of yaw from 0° to 9° in Figure 7 and also its manner of variation with Reynolds number (same Figure). The drag coefficient of the 5" Rocket, at 0° yaw, is approximately 15% less than that of the 4.5" Rocket. However, the difference becomes negligible for yaw angles of 5° and greater in the case of Model 25, and is reduced to an average of 7% for yaw angles of 2° and above for Model 21 of the 5" Rocket.

The maximum Water Tunnel velocity used in the tests was 60 ft/sec. This is equivalent, for the same Reynolds Number, to a velocity of 350 ft/sec in air with a temperature of 60° Fahrenheit. The ratio between prototype velocity in air and Water Tunnel velocity for this model for the same Reynolds number is 5.83.

Flow line drawings, Figure 8, show slight disturbances at the junction of the nose and fuse structure, and still smaller disturbance at the indents and screw openings. Turbulence at the rear is typical of a blunt-end afterbody and very similar to that of the 5" Rocket.

APPENDIX

DEFINITIONS

YAW ANGLE, ψ

The angle, in a horizontal plane, which the axis of the projectile makes with the direction of motion. Looking down on the projectile, yaw angles in a clockwise direction are positive (+) and in a counterclockwise direction, negative (-).

PITCH ANGLE, α

The angle, in a vertical plane, which the axis of the projectile makes with the direction of motion. Pitch angles are positive (+) when the nose is up and negative (-) when the nose is down.

LIFT, L

The force, in pounds, exerted on the projectile normal to the direction of motion and in a vertical plane. The lift is positive (+) when acting upward and negative (-) when acting downward.

CROSS FORCE, C

The force, in pounds, exerted on the projectile normal to the direction of motion and in a horizontal plane. The cross force is positive when acting in the same direction as the displacement of the projectile nose for a positive yaw angle, i.e., to an observer facing in the direction of travel, a positive cross force acts to the right.

DRAG, D

The force, in pounds, exerted on the projectile parallel with the direction of motion. The drag is positive when acting in a direction opposite to the direction of motion.

MOMENT, M

The torque, in foot pounds, tending to rotate the projectile about a transverse axis. Yawing moments tending to rotate the projectile in a clockwise direction (when looking down on the projectile) are positive (+), and those tending to cause counterclockwise rotation are negative (-). Pitching moments tending to rotate the projectile in a clockwise direction (when looking at the projectile from the port side) are positive (+), and those tending to cause counterclockwise rotation are negative (-).

In accordance with this sign convention a moment has a destabilizing effect when it has the same sign as the yaw angle or the opposite sign of the pitch angle.

In all model tests the moment is measured about the point of support. Moments about the center of gravity of the projectile have the symbol, M_{cg}.

NORMAL COMPONENT, N

The sum of the components of the drag and cross force acting normal to the axis of the projectile. The value of the normal component is given by the following:

$$N = D \sin \psi + C \cos \psi \qquad (1)$$

in which

N = Normal component in lbs

D = Drag in lbs

C = Cross force in lbs

ψ = Yaw angle in degrees

CENTER OF PRESSURE, CP

The point in the axis of the projectile at which the resultant of all forces acting on the projectile is applied.

CENTER-OF-PRESSURE ECCENTRICITY, e

The distance between the center of pressure (CP) and the center of gravity (CG) expressed as a decimal fraction of the length (l) of the projectile. The center-of-pressure eccentricity is derived as follows:

$$e = (l_{cp} - l_{cg}) \frac{1}{l} = \frac{1}{l} \frac{M_{cg}}{N} \qquad (2)$$

in which

e = Center-of-pressure eccentricity

l = Length of projectile in feet

l_{cg} = Distance from nose of projectile to CG in feet

l_{cp} = Distance from nose of projectile to CP in feet

COEFFICIENTS

The three force and moment coefficients used are derived as follows:

Drag coefficient, $$C_D = \frac{D}{\rho \frac{V^2}{2} A_D} \tag{3}$$

Cross force coefficient, $$C_C = \frac{C}{\rho \frac{V^2}{2} A_D} \tag{4}$$

Moment coefficient, $$C_M = \frac{M}{\rho \frac{V^2}{2} A_D l} \tag{5}$$

in which

D = Measured drag force in lbs

C = Measured cross force in lbs

ρ = Density of the fluid in slugs/cu ft = w/g

w = Specific weight of the fluid in lbs/cu ft

g = Acceleration of gravity in ft/sec^2

A_D = Area in sq ft at the maximum cross section of the projectile taken normal to the geometric axis of the projectile

V = Mean relative velocity between the water and the projectile in ft/sec

M = Moment, in foot-pounds, measured about any particular point on the geometric axis of the projectile

l = Overall length of the projectile in feet

CONTROL ANGLE

In considering the effect of rudders on static stability, either in yaw or pitch, the term "control angle" is used to denote the yaw below which a given rudder setting with opposite sign to the yaw will tend to return the projectile to zero yaw, and above which the yaw will further increase. The control angle is useful for indicating the effectiveness of rudders and for comparing the static stability of different projectiles with equal rudder settings.

RUDDER EFFECT

The total increase or decrease in moment coefficient, at a given yaw or pitch angle, resulting from a given rudder setting. This increase or decrease in moment coefficient is measured from the moment coefficient curve for neutral rudder setting.

REYNOLDS NUMBER

In comparing hydraulic systems involving only friction and inertia forces, a factor called Reynolds number is of great utility. This is defined as follows:

$$R = \frac{lV}{\nu} = \frac{lV\rho}{\mu} \tag{6}$$

in which

R = Reynolds number

l = Overall length of projectile, feet

V = Velocity of projectile, feet per sec

ν = Kinematic viscosity of the fluid, sq ft per sec = μ/ρ

ρ = Mass density of the fluid in slugs per cu ft

μ = Absolute viscosity in pound-seconds per sq ft

Two geometrically similar systems are also dynamically similar when they have the same value of Reynolds number. For the same fluid in both cases, a model with small linear dimensions must be used with correspondingly large velocities. It is also possible to compare two cases with widely differing fluids provided l and V are properly chosen to give the same value of R.

CAVITATION PARAMETER

In the analysis of cavitation phenomena, the cavitation parameter has been found very useful. This is defined as follows:

$$K = \frac{P_L - P_B}{\rho \frac{V^2}{2}} \tag{7}$$

in which

K = Cavitation parameter

P_L = Absolute pressure in the undisturbed liquid, lbs/sq ft

P_B = Vapor pressure corresponding to the water temperature, lbs/sq ft

V = Velocity of the projectile, ft/sec

ρ = mass density of the fluid in slugs per cu ft = w/g

w = weight of the fluid in lbs per cu ft

g = acceleration of gravity

Note that any homogeneous set of units can be used in the computation of this parameter. Thus, it is often convenient to express this parameter in terms of the head, i.e.,

$$K = \frac{h_L - h_B}{\frac{V^2}{2g}} \tag{8}$$

where

h_L = Submergence plus the barometric head, ft of water

h_B = Pressure in the bubble, ft of water

It will be seen that the numerator of both expressions is simply the net pressure acting to collapse the cavity or bubble. The denominator is the velocity pressure. Since the entire variation in pressure around the moving body is a result of the velocity, it may be considered that the velocity head is a measure of the pressure available to open up a cavitation void. From this point of view, the cavitation parameter is simply the ratio of the pressure available to collapse the bubble to the pressure available to open it. If the K for incipient cavitation is considered, it can be interpreted to mean the maximum reduction in pressure on the surface of the body measured in terms of the velocity head. Thus, if a body starts to cavitate at the cavitation parameter of one, it means that the lowest pressure at any point on the body is one velocity head below that of the undisturbed fluid.

The shape and size of the cavitation bubbles for a specific projectile are functions of the cavitation parameter. If p_B is taken to represent the gas pressure within the bubble instead of the vapor pressure of the water, as in normal investigations, the value of K obtained by the above formula will be applicable to an air bubble. In other words, the behavior of the bubble will be the same whether the bubble is due to cavitation, the injection of exhaust gas, or the entrainment of air at the time of launching.

The following chart gives values of the cavitation parameter as a function of velocity and submergence in sea water.

GENERAL DISCUSSION OF STATIC STABILITY

Water tunnel tests are made under steady flow conditions, consequently the results only indicate the tendency of the steady state hydrodynamic couples and forces to cause the projectile to return to or move away from its equilibrium position after a disturbance. Dynamic couples and forces including either positive or negative damping are not obtained. If the hydrodynamic moments are restoring the projectile, then it is said to be statically stable, if nonrestoring, statically unstable. In the discussion of static stability the actual motion following a perturbation is not considered at all. In fact, the projectile may oscillate continuously about an equilibrium position without remaining in it. In this case it would be statically stable, but would have zero damping and hence, be dynamically unstable. With negative damping a projectile would oscillate with continually increasing applitude following an initial perturbation even though it were statically stable. Equilibrium is obtained if the sum of the hydrodynamic, buoyant, and propulsive moments equal zero. In general, propulsive thrusts act through the center of gravity of the projectile so only the first two items are important.

If a projectile is rotating from its equilibrium position so as to increase its yaw angle positively, the moment coefficient must increase negatively (according to the sign convention adopted) in order that it be statically stable. Therefore, for projectiles without controls or with fixed control surfaces, a negative slope of the curve of moment coefficient vs yaw gives static stability and a positive slope gives instability. For a projectile without controls, static stability is necessary for a successful flight unless stability is obtained by spinning as in the case of rifle shells. For a projectile with controls, stabilizing moments can be obtained by adjusting the control surfaces, and the slope of the moment coefficient, as obtained with fixed rudder position, need not give static stability. Where buoyancy either acts at the center of gravity or can be neglected, equilibrium is obtained when the hydrodynamic moment coefficient equals zero. For symmetrical projectiles this occurs at zero yaw angle, i.e., when the projectile axis is parallel to the trajectory. For nonsymmetrical projectiles, such as a torpedo when the rudders are not neutral, the moment is not zero at zero yaw but vanishes at some definite angle of attack. Where buoyancy cannot be neglected equilibrium is obtained when $C_M = -C_{Buoyancy}$, and the axis of the projectile is at some angle with the trajectory.

For symmetrical projectiles the degree of stability or instability can be obtained from the center-of-pressure curves. If the center of pressure falls behind the center of gravity, a restoring moment exists giving static stability. If the center of pressure falls ahead of the center of gravity, the moment is nonrestoring, and the projectile will be statically unstable. The degree of stability or instability is indicated approximately by the distance between the center of gravity and the center of pressure. In general, for nonsymmetrical projectiles, the cross force or lift is not zero when the moment vanishes so that the center of pressure curve is not symmetrical and the simple rules just stated cannot be used to determine whether or not the projectile will be stable. In such cases careful interpretation of the moment curves is a more satisfactory method of determining stability relationship.

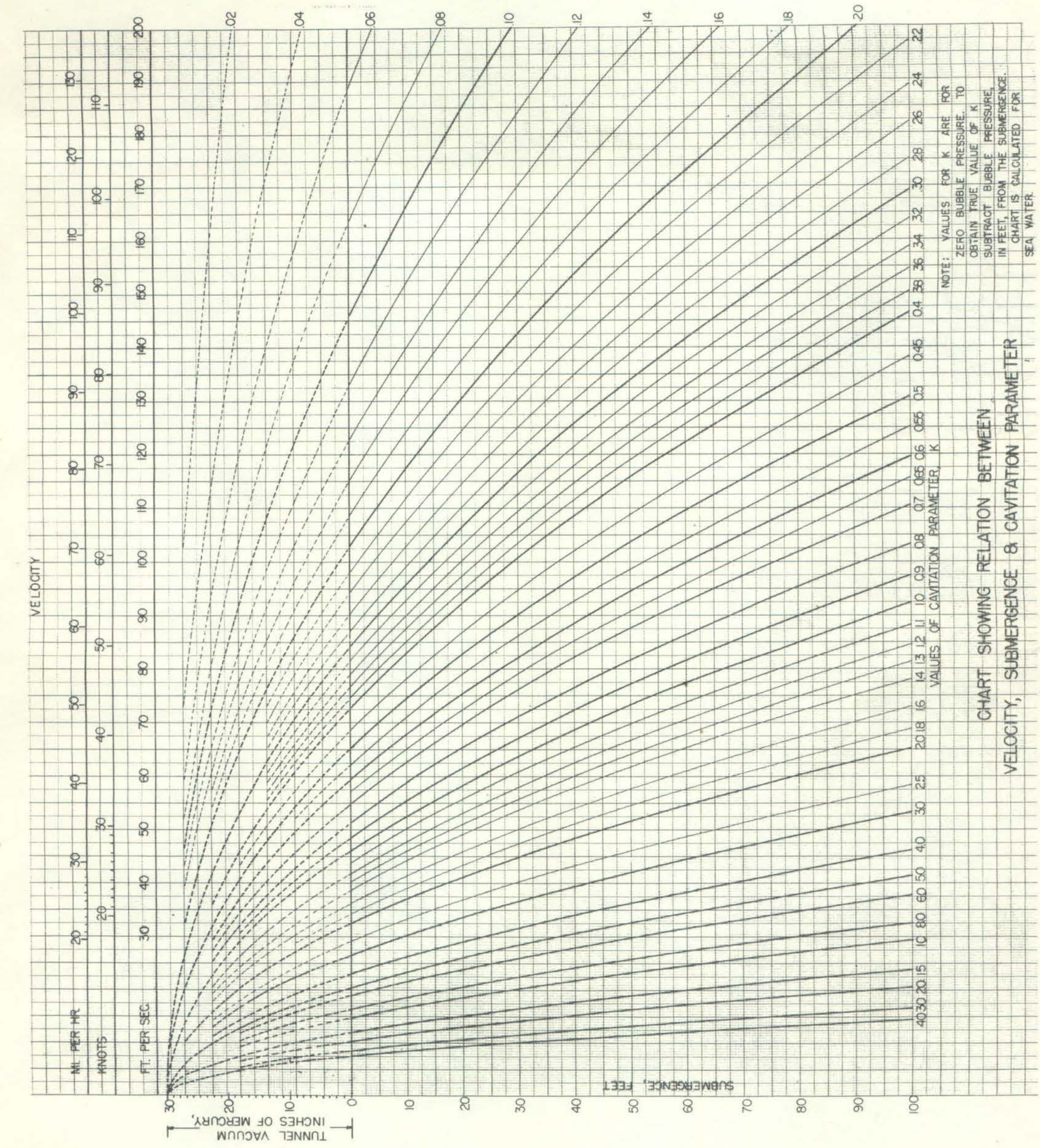


CHART SHOWING RELATION BETWEEN
VELOCITY, SUBMERGENCE & CAVITATION PARAMETER
NOTE: VALUES FOR K ARE FOR ZERO BUBBLE PRESSURE. TO OBTAIN TRUE VALUE OF K SUBTRACT BUBBLE PRESSURE, IN FEET, FROM THE SUBMERGENCE. CHART IS CALCULATED FOR SEA WATER.
VALUES OF CAVITATION PARAMETER, K
VELOCITY
MI. PER HR.
KNOTS
FT. PER SEC.
SUBMERGENCE, FEET
TUNNEL VACUUM INCHES OF MERCURY